Taphonomy and Palaeoenvironmental Interpretation of a Late Holocene Deposit from Black's Point Sinkhole, Venus Bay, S.A.

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The deposit from Black's Point Sinkhole, Venus Bay Conservation Park, SA, represents a continuous 3500 year palaeontological and geological record for the late Holocene. Taphonomic analysis established the sinkhole as a pitfall trap. Palaeoenvironmental settings were deduced by analysing sediments and fauna. Age was assessed using carbon dating. Evidence suggests that around 4000BP precipitation was greater than present and the environment was dominated by closed canopy forests with an understorey and nearby mud flats. During this period fauna including *Isoodon obesulus* and *Bettongia penicillata* accumulated. From approximately 4000BP to 1000BP the climate became warmer, drier and more variable. During this period sea level retreated, forests became more open and the understorey was greatly reduced. Species including *Perameles bougainville*, *Pseudomys bolami*, *Sminthopsis dolichura*, *Sminthopsis hirtipes* and *Thylacinus cynocephalus* appeared and/or became dominant. A carbon date associated with a *T. cynocephalus* tooth suggests an age of 3030±60BP making it the youngest mainland occurrence recorded. Around 1000BP precipitation increased and climate became slightly less variable, resulting in an increase in forest and understorey density. *Macrotis lagotis* appeared and *I. obesulus* returned while *P. bougainville* and many arid zone species retreated. These species changes can be associated with the increase in density of forest and understorey during the period of increased precipitation.

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INTRODUCTION

Late Pleistocene to Holocene fossil deposits provide a record of faunal communities and, by inference, floral communities that occupied their surrounding area prior to European settlement (Baynes 1987). The study of such fossil deposits is of vital importance, as it increases our knowledge and understanding of past communities, and provides a baseline against which to measure change. The aim of this study was to use the sedimentological and palaeontological evidence from the Black's Point sinkhole within the Venus Bay Conservation Park, Eyre Peninsula, SA to reconstruct the regional history of environmental change before European settlement.

Processes that affect fossils tend to bias against, rather than for, preservation. The *prima facie* assumption therefore, is that all fossil deposits are a biased representation of the community from which they were drawn. Many authors (e.g. Douglas et al. 1966; Voorhies 1969; Peterson 1977; Behrensmeyer 1978, 1982, 1991, 1993; Behrensmeyer et al. 1979; Behrensmeyer and Hill 1980; Behrensmeyer and Kidwell 1985, 1979; King and Graham 1981; Wakefield 1982; Andrews and Nesbit Evans 1983; Hoffman 1988; Andrews 1990; Baird 1991; Lyman 1994a, b; Simms 1994) have investigated the biases

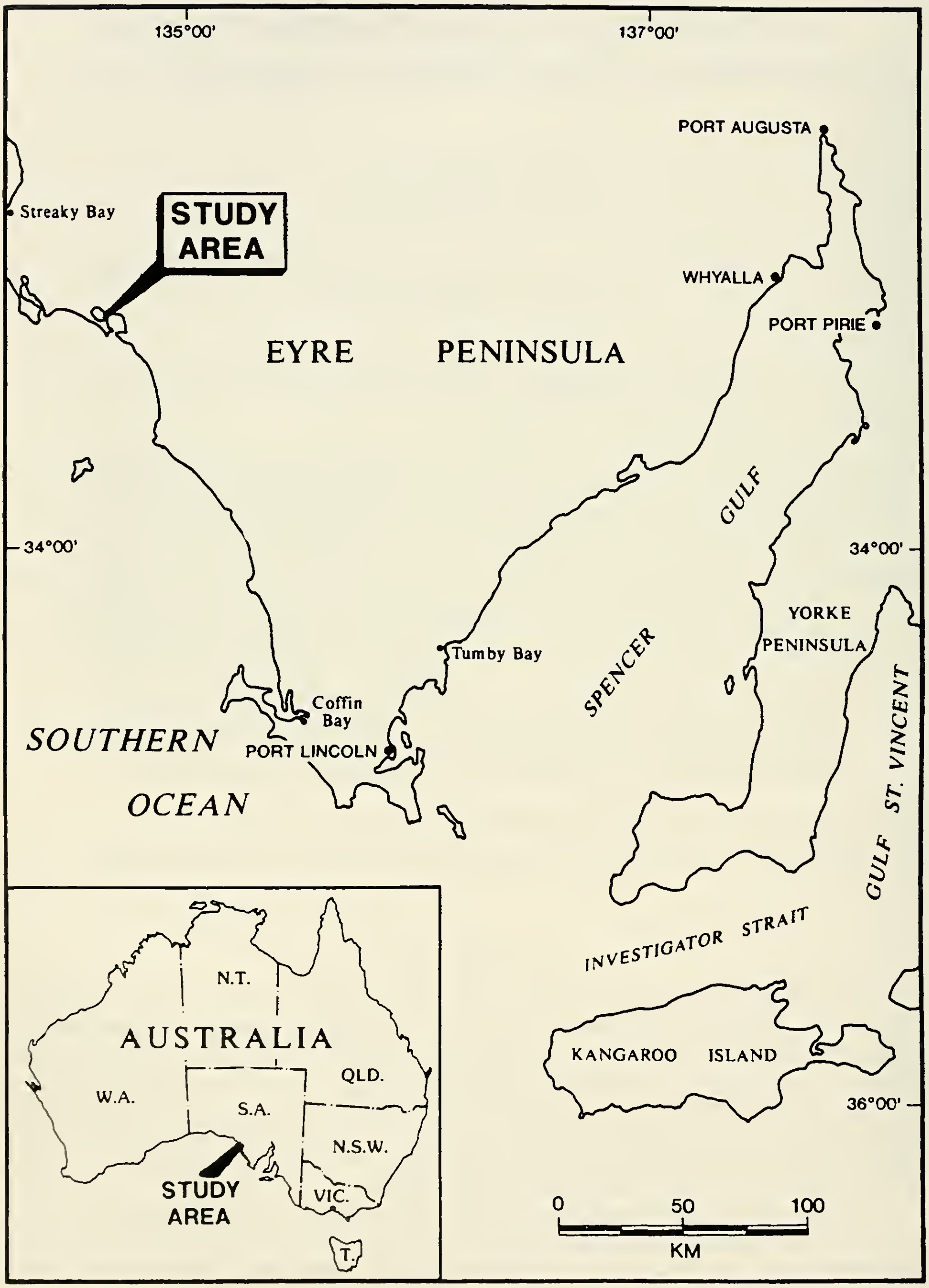

Figure 1. Location map of Black's Point sinkhole, Venus Bay.

affecting bone assemblages and how they can be recognised. Biasing processes include environmental and substrate conditions proximal to a death site, the mode of accumulation, hydraulic transport, weathering, bioturbation, animal size, animal lifespan, time averaging (processes such as erosion and redeposition by which fossils of different age are concentrated so that they appear to be contemporaneous) and excavation practices. This study investigates the taphonomic biases present during accumulation of the Black's Point sinkhole deposit by analysing samples of the fossils and sediments.

This study coincides with a Department of Environment and Natural Resources (DENR) program to reintroduce the brush-tailed Bettong (*Bettongia penicillata*) to the park. It is of interest to DENR to determine what other locally extinct species might also be reintroduced.

Location

Black's Point Sinkhole is located at latitude 33°(10'95" S and longitude 134°(26'84" E on an island within Venus Bay Conservation Park (established in 1976). Venus Bay is on the upper west coast of Eyre Peninsula near the eastern edge of the Great Australian Bight (Fig. 1). The island lies inside Venus Bay proper and has been connected to the mainland in geologically recent time by a tombolo. It is not named on maps, but is locally known as Black's Point, hence the sinkhole's name.

Black's Point sinkhole is approximately 4m deep and somewhat bell shaped (Fig. 2). Its non-parallel walls are about 1.2m apart at the floor but narrow rapidly near the surface to an approximately ovoid entrance measuring 0.6m by 0.9m. The entrance to Black's Point sinkhole lies approximately 6m above mean sea level and 53m from the sheltered bay on a gentle north-westerly slope of approximately 8 degrees. The area is surrounded by water but protected from the open ocean by the 50–100 metre high limestone/calcaranite cliffs of Cape Weyland (Fig. 1).

Black's Point sinkhole has an interesting history. Some time ago a well was dug inside the sinkhole, presumably by a farmer searching for fresh water. The sediment removed was left in a spoil heap near its entrance. The sinkhole entrance was later rediscovered by Conservation Park biologists who covered it with wire mesh in the belief that it posed a danger to the brush-tailed bettongs being released in the park. In the process they noted fossils in the spoil heaps and realised the potential of deducing the park's original (pre-European) fauna. A large proportion of sediment had been removed from the sinkhole by the well sinking operation, but sediment varying in thickness from 100 to 790 mm, was left *in situ* around the walls (Fig. 2) from which samples could be taken.

METHODS

Excavation

The strata within Black's Point sinkhole were divided into seven 20cm units and one 30cm unit using the lip of the sinkhole mouth as a datum. Excavation was confined to a 0.5m wide column of sediment from the NEE sinkhole wall that was chosen for its high fossil content. Excavation levels were defined with steel pegs and twine using a spirit level and tape measure to ensure accuracy. The eight levels were then labelled A through to H from top to bottom (Fig. 2). Fossiliferous sediment was excavated using dental picks, trowels, soft brushes and dust pans. A large tray was inserted at the base of the level being excavated to prevent contamination of lower levels. Sediment was lifted to the surface by hand using a 10kg bucket (as an arbitrary unit measure) which were emptied into labelled polythene bags. The fossiliferous sediment was wet sieved by Mr G. Medlin using nested sieves of 5mm, 2.5mm and 1.25mm mesh. Rocks were removed

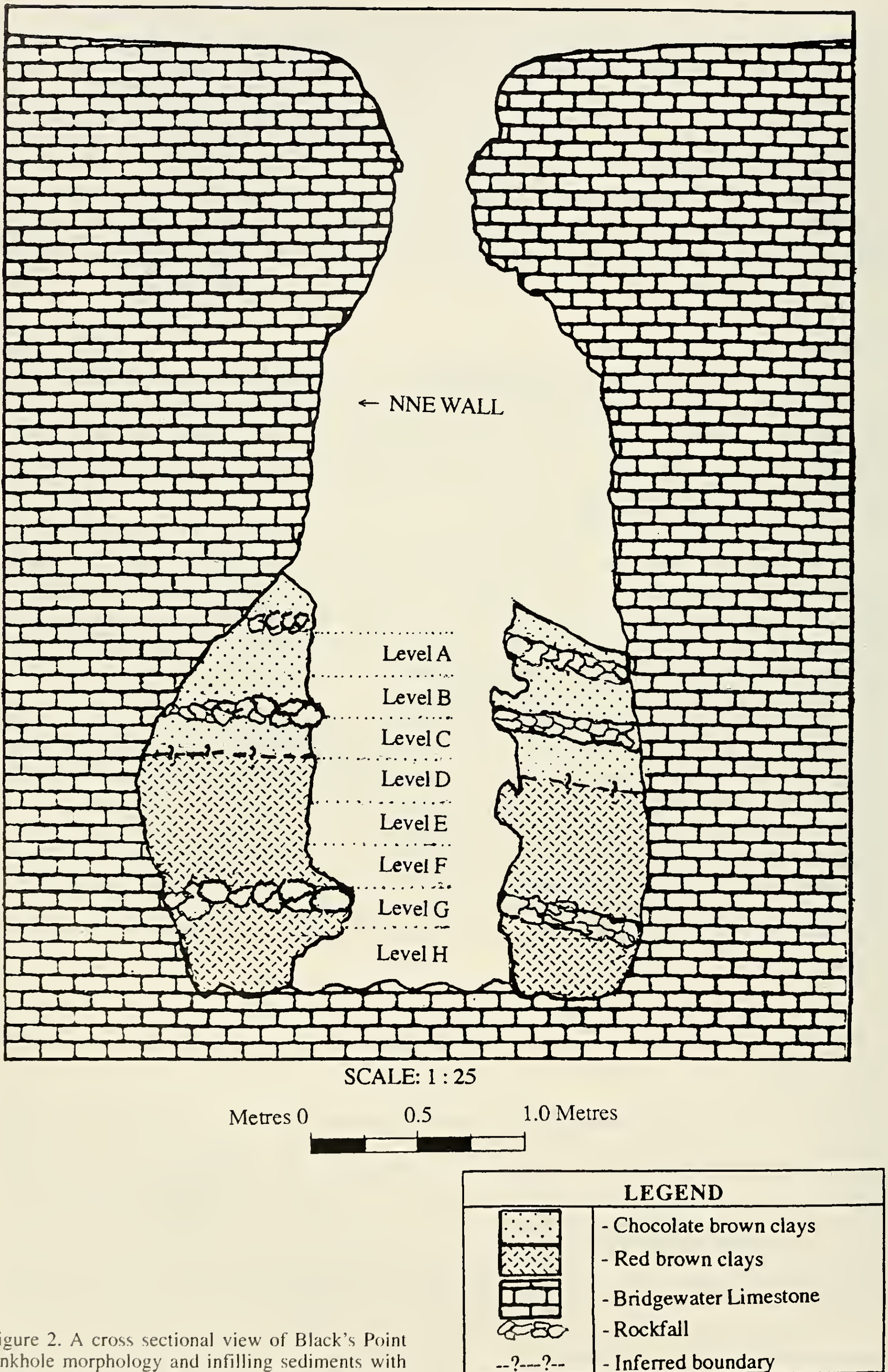

Figure 2. A cross sectional view of Black's Point sinkhole morphology and infilling sediments with excavation levels indicated.

and fossils were allowed to dry. All skeletal elements were sorted and collected from the remaining sediment and rock using a small brush and forceps, then stored in labelled vials for identification and use in quantitative analysis.

Faunal Analysis

Small mammal fossil remains were viewed using a binocular microscope following the procedure described in Andrews (1990). Specimens were identified by comparison with published data and reference material accessed from The Flinders University of South Australia (FUSA), the South Australian Museum (SAM) and the collection of Dr M Smith. Once identified, specimens were allocated reference numbers and stored in vials labelled with the species name, level of origin, source and reference number. They have now been lodged with the SAM mammal collection.

Taphonomic Analysis

Using the methods of Andrews (1990), the numbers of skeletal elements per level (Ni) were counted and their relative abundance (Ri) calculated, based on comparison with the minimum numbers of individuals (MNI) multiplied by the expected numbers of each element (Ei). MNI is calculated by counting the most abundant skeletal element present and dividing it by the number of those elements present in a complete skeleton and Ei is calculated by multiplying MNI by the number of each element present in a complete skeleton.

$$Ri = \frac{Ni}{MNI(Ei)} \times 100\%$$

Proportions of elements are indicated by four indices: (a) post-crania in relation to crania were shown by an index comparing five post-cranial elements (humerus, radius, ulna, femur and tibia) to numbers of mandibles, maxillae and isolated molars; (b) a second index compares numbers of humeri and femora to mandibles and maxillae; (c) loss of distal limbs is shown by an index comparing numbers of tibiae and radii with numbers of femora and humeri; (d) relative proportions of isolated teeth were calculated with reference to numbers of empty alveolar spaces in the jaw such that proportions of more than 100% indicate relative loss of jaws and less than 100% relative loss of teeth; this index was calculated separately for incisors and molars.

Breakage of post-cranial elements was based on separation of each into complete, proximal, shaft and distal segments, with the proportions of each category calculated against the whole.

Breakage of skulls was indicated by proportions of complete skulls, proportions of maxillae retaining the zygomatic process, and molars and incisors lost from the maxilla.

Breakage of mandibles was indicated by proportions of complete half-mandibles (with no distinction made between left and right), proportions of mandibles with inferior borders broken, and molars and incisors lost from the mandible.

The age frequency distribution of small mammals was determined by attributing each cranial specimen to one of five age classes in accordance with the wear observed on teeth. Age classes are defined as: (1) very young, no wear on molars, (2) young, small amount of molar cusp wear, (3) middle aged, molar cusps worn near smooth with dentine clearly visible, (4) old, molar cusps almost worn away completely with only strips of enamel remaining, (5) very old, molars very worn with only a rim of enamel around a basin of dentine remaining. A negligible number of broken teeth and no evidence of element digestion was observed so these categories of information were not investigated.

TABLE 1

Minimum Numbers of Individuals (MNI) for Mammals from different levels in Black's Point Sinkhole, Venus Bay.

Stratigraphic Level	**A**	**B**	**C**	**D**	**E**
Sample Size (x10kg)	1	4	4	4	1
Muridae Indet.*	9	232	111	332	18
Rattus sp.	2		12	8	
Rattus fuscipes	4	122	93	71	4
Pseudomys sp.	2	28	73	35	4
Pseudomys australis		21	2	5	
Pseudomys shortridgei		9	16	3	
Pseudomys gouldii		1	2	1	
Pseudomys bolami		2			
Pseudomys occidentalis			1		
Notomys sp. cf.. *N. mitchelli*		2	1		
Total Muridae MNI	17	232	200	332	26
Cercartetus sp. cf. *C. concinnus*		2			
Total Phalangeroidea MNI			2		
Peramelidae indet.	2	3	2	17	
Isoodon obesulus	2			18	
Perameles bougainville		4	9		
Total Peramelidae MNI	4	7	11	35	0
Macrotis lagotis	1				
Total Thylacomyidae MNI	1	0	0	0	0
Bettongia indet.	1	3			
Bettongia penicillata	3	6	3	7	
Macropus eugenii	1	4	8		
Total Macropodoidea MNI	5	13	11	7	0
Sminthopsis sp.		5	1	3	1
Sminthopsis sp. cf. S *hirtipes*		1	2		
Sminthopsis psammophila		1	1		
Sminthopsis sp. cf. *S. dolichura*	6	1			
Parantechinus apicalis			1	1	
Phascogale tapoatafa				1	
Dasyurus sp. cf.. *D. geoffroii*			1	1	
Thylacinus cynocephalus			1		
Total Dasyuroidae MNI	0	13	8	6	1
Total N^{0} of Species	6	13	16	10	3
TOTAL MNI	**33**	**265**	**232**	**377**	**27**

* Muridae Indet. MNI is based on individual insisors which often represents the total maximum murid MNI.

Sedimentological Analysis

Sediment from each surveyed level of Black's Point sinkhole was petrographically analysed in thin section to determine differences in composition grain size and grain shape in attempt to identify the sediment's source of origin.

Carbon Dating

All charcoal fragments were collected for each level to use in carbon dating. A series of five carbon dates were obtained for levels A, C, D, E and G from the Quaternary Dating Research Centre at the Australian National University (ANU). Several small fragments of charcoal were collected and added together for each level to make a sample large enough for dating.

RESULTS

Faunal Analysis

Table 1 presents the mammal fauna and the total number of species identified from each level of Black's Point sinkhole. It also includes the MNI calculated for each species, the MNI calculated for each genus and the total MNI for each level. The discovery of a single thylacine first upper right molar ($M^1/$) and two mandibles from the dibbler (*Parantechinus apicalis*) are of particular interest.

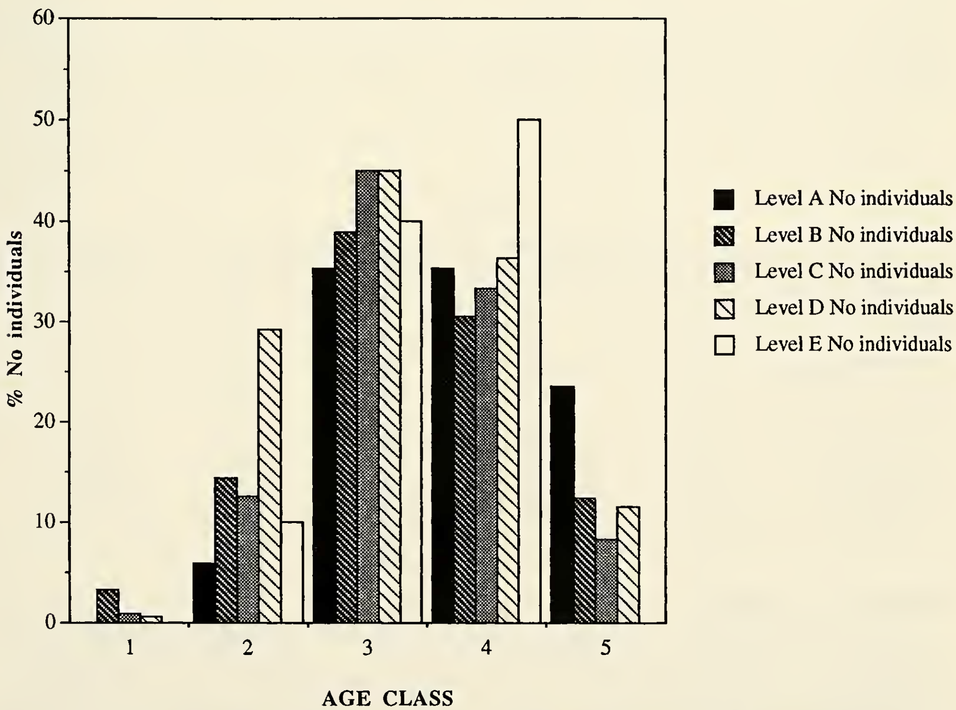

Figure 3. Small mammal age frequency distribution where category 1 = juvenile, 2 = subadult, 3= adult, 4 = old, and 5 = very old.

TABLE 2

The quantity (No) and relative abundances (Ri) of small mammal skeletal elements recovered from different levels of Black's Point sinkhole.

Level	A		B		C		D		E	
Sample Size (x10kg)	1		4		4		4		1	
Skeletal Elements	No	Ri	No	Ri	No	Ri	No	Ri	No	Ri
Mandibles	12	31.60	401	75.70	418	90.10	390	51.80	11	28.90
Maxillae	14	36.80	345	65.10	336	72.40	207	27.50	13	34.20
Incisors	27	35.50	312	29.40	315	33.90	1221	81.00	61	80.30
Molars	76	33.30	577	18.10	375	13.50	821	18.10	112	49.10
Femora	12	31.60	152	28.70	262	56.50	125	16.60	6	15.80
Tibia	16	42.10	93	17.50	251	54.10	166	22.00	34	89.50
Pelvi	24	63.20	134	25.30	194	41.80	92	12.20	8	21.10
Calcanea	12	31.60	19	3.40	13	2.80	41	5.40	11	28.90
Astragali	7	18.40	23	4.30	13	2.80	11	1.50	5	13.20
Humeri	7	18.40	148	27.90	250	46.30	168	22.30	12	31.60
Radii	5	13.20	8	1.50	26	5.60	10	1.30	2	5.30
Ulnae	16	42.10	91	17.20	68	14.70	110	14.60	5	13.20
Scapulae	14	36.80	97	18.30	36	7.80	28	3.70	2	5.30
Ribs	51	11.20	293	5.00	199	3.60	373	4.10	5	1.20
Vertebrae	154	20.30	258	2.40	102	1.10	82	0.50	51	2.00
Mean Ri		31.07		22.65		29.80		18.89		27.97

TABLE 3

Indices indicating proportions of skeletal elements.

Stratigraphic Level	A	B	C	D	E
Index					
% post crania/crania	87.8	65.2	122.7	65.5	69.4
%fem.+hum./man.+max	73.1	40.2	67.9	45.4	75.0
% tib.+rad./fem.+hum.	110.5	47.0	55.1	68.1	194.4
% isolated molars	166.0	40.1	22.3	64.3	183.6
% isolated incisors	135	54.4	58.4	275.6	254.2

Taphonomic Analysis

The results for the taphonomic analysis of Black's Point sinkhole fauna are shown in Tables 2–5 and Figs 2 and 3. Levels F, G and H were not included due to small yields and sample sizes. Mammal fossils appear most abundant in the upper levels but are common throughout the sinkhole strata. Level E was the lowest unit analysed and contains mostly isolated teeth and tibia (Table 2). The proportion of post-crania to crania is moderate (Table 3), while breakage for both cranial and post-cranial elements is high (Tables

4 and 5). The proportion of isolated teeth suggest a relative loss of jaws. No elements show the affects of digestive dissolution, polishing or rounding, but many show the effects of mild chemical weathering and some root dissolution.

Fossils appear better preserved in level D than level E, but proportions of post-crania to crania are very similar (Table 3). Mandibles and maxillae are relatively more abundant (Table 2) but the degree of both cranial and post-cranial breakage is similar (Table 4). The proportion of isolated molars is less than 100% suggesting a relative loss of teeth, but the proportion of isolated incisors is much greater than 100% suggesting a relative loss of jaws (Table 3).

TABLE 4

Type and extent of breakages in small mammal long bones extracted from different levels of Black's Point sinkhole.

Stratigraphic Level	A		B		C		D		E	
Breakage	No.	%	No.	%	No.	%	No.	%	No.	%
Humeri										
Complete	1	14.3	81	54.6	131	52.4	19	14.1	0	0
Proximal	4	57.1	63	42.6	109	43.6	110	81.5	9	75
Shaft	1	14.3	2	1.4	6	2.4	5	3.7	3	25
Distal	1	14.3	2	1.4	4	1.6	1	0.7	0	0
Ulnae										
Complete	2	12.5	19	20.9	10	14.7	1	0.9	0	0
Proximal	14	87.5	72	79.1	58	85.3	108	98.2	5	100
Shaft	0	0	0	0	0	0	1	0.9	0	0
Distal	0	0	0	0	0	0	0	0	0	0
Femora										
Complete	9	75	61	39.9	129	49.3	21	16.4	0	0
Proximal	3	25	82	53.6	124	47.3	100	78.1	5	83.3
Shaft	0	0	0	0	0	0	3	2.3	1	16.7
Distal	0	0	9	5.9	9	3.4	4	3.2	0	0
Tibia										
Complete	5	31.25	24	15.7	37	14.7	10	6.0	0	0
Proximal	5	31.25	54	35.3	121	48.0	56	33.7	8	23.5
Shaft	5	31.25	27	17.7	53	21.0	72	43.4	25	73.5
Distal	1	6.25	48	31.3	41	16.3	28	16.9	1	3.0
Radii										
Complete	5	100	8	100	26	83.9	10	55.6	2	100
Proximal	0	0	0	0	1	3.2	3	16.7	0	0
Shaft	0	0	0	0	0	0	0	0	0	0
Distal	0	0	0	0	4	12.9	5	27.8	0	0

TABLE 5

Small mammal Cranial Element preservation for different level of Black's Point sinkhole.

Stratigraphic Level	A	B	C	D	E
Skull Breakage:					
% complete	0	0	0	0	0
% maxillae with zygoma.	3.6	66.4	54.7	38.8	23.1
% maxilla molar loss:	27.4	34.8	45.3	36.9	42.3
% maxilla incisor loss	85.7	99.7	100	100	100
Mandible Breakage:					
% complete	8.3	0	0.3	0	0
% inferior border broken	58.3	38.9	21.4	54.1	100
% mandible molar loss:	33.3	32.8	31.8	35.0	42.4
% mandible incisor loss	66.7	79.8	48.8	60.5	100

Skeletal element relative abundance is higher for level C than for levels D and E with mandibles showing greater than 90% relative abundance and many other elements showing greater than 40% relative abundance (Table 2). The proportion of post-cranial to cranial elements is significantly higher in level C than levels D and E, but other indices of skeletal element proportions are comparable. The proportion of isolated molars and incisors suggests a relative loss of teeth (Table 3). The degree of breakage is lower in level C than in levels D and E (Tables 4 and 5).

The fossils of level B are well preserved and the proportion of isolated molars and incisors is less than 100% suggesting a relative loss of teeth. The proportion of post-cranial to cranial elements is lower than obtained for level C, but other indices of proximal and distal post-cranial elements are very similar (Table 3). The degree of breakage is comparable to that seen in level C (Table 4 and 5).

The fossils of level A, the uppermost level analysed, show high post depositional weathering and high levels of breakage (Tables 4 and 5). The proportions of isolated molars and incisors are both greater than 100% indicating a relative loss of jaws. This is supported by the degree of mandible and maxillae breakage.

The age frequency distribution attained for all levels (Fig. 3) is slightly skewed toward aged individuals but generally reflects those age group proportions found in a living community.

Sediments and Stratigraphy

Two major stratigraphic units occur in Black's Point sinkhole. The lower unit which extends from the top of Level D to the floor consists of thick red-brown amorphous clays. No evidence of lamination or reworking was observed. The upper unit which extended from the bottom of Level C to above Level A consists of chocolate brown silty clay which again showed no sedimentary structure. The two units are separated by a very sharp contact.

When petrographically analysed level E was observed to be composed of 58% clay minerals, 32% gypsum, 7% micro-crystalline calcite (micrite) and 3% opaques (charcoal). Non-clay sized grains were fine, sub angular and moderately to poorly sorted. Level D contained 55% clay minerals, 35% gypsum, 5% micrite and 5% opaques (charcoal). Non-clay sized grains were fine, sub-rounded and moderately to well sorted. Some 2–3mm clay nodules and calcite gravel were also observed, as were fossil root casts.

Petrographic analysis showed that level C is composed of 50% clay minerals, 35% gypsum, 5% micrite and 10% opaques (charcoal). Sand sized grains are predominantly fine and sub-rounded to rounded. Some coarse clay nodules and calcite gravel also occur. The sand sized sediments of level B are fine grained, rounded to sub-rounded and moderately sorted. They are composed of 40% clay minerals, 40% gypsum, 15% micrite and 5% opaques (charcoal). Sediments from level A consist of 50% clay minerals, 35% gypsum, 10% micro-crystalline calcite (micrite) and 5% opaques (charcoal). Sand sized grains are fine and moderately sorted. Gypsum grains appear sub-angular to sub-rounded, while all other grains appear well rounded. In all levels gypsum grains are fragmentary suggesting that they have been transported into the sinkhole and are not authigenic.

TABLE 6

Summary of Results obtained for Radiocarbon Dating of Charcoal collected from different levels of Black's Point sinkhole.

Code Number	Date	Level of Origin
ANU-9893	1160±60 BP	A
ANU-9892	3030±60 BP	C
ANU-9891	4440±70 BP	D
ANU-9890	4040±140 BP	E
ANU-9889	4300±290 BP	G

Dating

The radiocarbon dates obtained from ANU can be seen in Table 6. It shows a partial succession in age from the youngest at the highest stratigraphic level dated, to the oldest in a lower stratigraphic level, but the three lower most dates obtained are not in sequence. Carbon dates obtained for level D and level G are not significantly different, but the age of level D is significantly older than level E. This suggests that the lower strata may have been reworked, although there are no supporting sedimentary structures. Alternatively, contamination of charcoal used to obtain the two lower-most dates with younger material may have occurred. Because several charcoal fragments were used to obtain a workable sample size, spurious grains that originated from higher levels may have been included. Charcoal samples from the lower strata are especially prone to this as their sample sizes were very small.

Contaminated charcoal samples would be subject to an averaging effect that would significantly alter the age estimate obtained. Only a small quantity of 'young' charcoal would be needed to decrease an age estimate obtained from a contaminated sample of 'old' charcoal. Radiocarbon dates indicate that the majority of sediments and fossils sampled from Black's Point sinkhole have not been reworked. It is therefore assumed that any change in fauna, or any disharmonious species pairs do not result from the mixing of non-contemporaneous sediments or time averaging.

Charcoal associated with the thylacine tooth recovered from level C was dated at 3030±60BP suggesting the youngest date of a mainland thylacine.

DISCUSSION

Accumulation of Black's Point sinkhole fauna

The morphology of Black's Point sinkhole renders it unsuitable for den use by either mammalian or avian predators. This is supported by the lack of predator tooth marks, digestive dissolution, rounding and/or polishing of fossils. Indices used to compare proportions of skeletal elements (Table 3) show no clear preference in the destruction of cranial elements compared with post-cranial elements, or proximal post-cranial elements compared with distal post-cranial elements. This indicates that the deposit was not accumulated by a mammalian or avian predator, both of which preferentially digest and/or break proportions of their prey skeletons (Andrews and Nesbit Evans 1983, Andrews 1990). The age frequency distribution (Fig. 3) obtained for all levels suggests an accumulative or chance collection mode rather than a selective one expected of predators.

Elements from all three Voorhies groups (Voorhies 1969) are well represented on all levels and no evidence of abrasive wear was observed. This suggests that fluvial transport was not the primary mode of fossil collection.

As can be seen in Table 1 the size and species of animals present for all levels is highly diverse, ranging from large animals (> 20kg) to very small animals (< 20g) (Strahan 1988). Many of the species listed in Table 1 are still thought to inhabit Eyre Peninsula, but it is of particular interest to note the collection of thylacine and dibbler specimens. The deposit was initially considered too recent to collect megafauna specimens, while the dibbler is a threatened species that has not previously been recorded from Eyre Peninsula fossil deposits, but is common in Western Australia.

Some of the species present are nocturnal while others are diurnal. Some are predators while others are herbivores and still others are omnivores. The vast majority of species present are terrestrial ground dwellers with only a few scansorial and arboreal species present in small numbers.

This indicates a collection mode that does not significantly bias for body size, feeding habits or activity schedules, but does bias against species' habitual dwelling areas. The evidence obtained suggests that the primary mode of collection for the fossils excavated from Black's Point sinkhole was a pitfall trap.

In a pifall trap assemblage one might expect to find more articulated or at least associated elements within the undisturbed sediment excavated. The lack of associated skeletons suggests that a degree of secondary taphonomic biasing has occurred. This is believed to be the result of minor hydraulic sorting and compaction. In the winter months after soil saturation has occurred, runoff water cascades into the sinkhole, eroding and transporting the surface sediment a short distance towards the sides of the sinkhole before percolating away. Element disassociation might also result from the activities of trapped animals before their death. The moderate to high levels of chemical weathering observed on all specimens suggests that this water was mildly acidic. This weathering, combined with the occasional root mark and frequent discrete layers of roof fall material (Fig. 2) show that the sinkhole entrance was becoming larger with time.

Palaeoenvironmental Interpretation

Pitfall traps are extremely useful for interpreting past environmental conditions because unlike other collection modes such as predators or fluviatile systems they are geographically stationary. One can therefore assume that compositional variations will be the result of changing environmental conditions rather than changing collection agents. Assuming uniformitarian principles apply, a record of environmental conditions may be obtained by examining the preferred conditions of animals that once lived proximal to, and were trapped in a pitfall. Through analysing the fossils from each level of Black's Point sinkhole strata, a story of past environmental conditions and changes begins to emerge.

TABLE 7

Preferred habitats of mammals from different levels in Black's Point Sinkhole, Venus Bay.

Stratigraphic Level	A	B	C	D	E
Sample Size (x10kg)	1	4	4	4	1
Ubiquitous species					
Thylacinus cynocephalus			✓		
Percentage ubiquitous species	**0**	**0**	**7**	**0**	**0**
Forest species					
Rattus fuscipes	✓	✓	✓	✓	✓
Pseudomys occidentalis			✓		
Bettongia penicillata	✓	✓	✓	✓	
Macropus eugenii	✓	✓	✓		
Cercartetus sp. cf. *C. concinnus*	✓				
Isoodon obesulus	✓			✓	
Phascogale tapoatafa				✓	
Percentage forest species	**66.7**	**30.8**	**28.6**	**40**	**66.6**
Heathland species					
Pseudomys shortridgei		✓	✓	✓	
Parantechinus apicalis			✓	✓	
Percentage heathland species	**0**	**7.8**	**12.5**	**20**	**0**
Desert species					
Pseudomys australis		✓	✓	✓	
Pseudomys gouldii		✓	✓	✓	
Pseudomys bolami		✓			
Notomys sp. cf.. *N. mitchelli*		✓	✓		
Sminthopsis sp. cf. S *hirtipes*		✓	✓		
Perameles bougainville		✓	✓		
Macrotis lagotis	✓				
Sminthopsis psammophila		✓	✓		
Sminthopsis sp. cf. *S. dolichura*	✓	✓		✓	
Dasyurus sp. cf.. *D. geoffroii*			✓	✓	
Percentage Desert species	**16.7**	**61.5**	**50**	**30**	**33.3**

The fossil faunas and sediments of levels D and E are from the same stratigraphic unit and are similar in preservation and breakage patterns, thus suggesting that they were collected under very similar environmental conditions. Level E lacks many of the species recorded in level D, but this is considered a function of level E's sample size (see Table 1). *R. fuscipes* and *P. tapoatafa* both commonly occupy forests. *P. tapoatafa* is arboreal, suggesting the presence of tall trees. *P. shortridgei* populates heath-land, while *I. obesulus* is known to occur in both forests and heathland, and like *B. penicillata*, prefers areas with a low shrubby ground cover or understorey. *P. gouldii* inhabits hummocky grassland, while *P. australis* prefers rocky desert and *D. geoffroii* is considered ubiquitous (Walton 1988) (Table 7).

Several allopatric species pairs occur in level D (Appendix I). Several tropical to temperate heath and forest dwelling species coexisted with rocky desert and hummock grassland species, suggesting the environment was more equitable than at present and that a greater range of niches were available (Lundelius 1983). The assimilation of these different ecologies indicate an environment composed of broken temperate forest-woodland with a low shrubby understorey, interspersed with grassland-heathland and rocky or alluvial surfaced patches, that requires a higher level of precipitation than is available under present conditions. The high proportion of detrital gypsum present in the sediments of these levels suggests that an evaporitic setting also existed nearby. This may have taken the form of a sabkha mudflat or a playa lake from which gypsum was eroded by the wind.

The fauna identified in levels C and B indicate a change in palaeoenvironmental conditions. *D. geoffroii* and *T. cynocephalus* are considered ubiquitous, and are therefore of little interpretive use, but *R. fuscipes*, *N. mitchelli* and *P. occidentalis* are known to mainly populate temperate forests and shrublands. *M. eugenii*, *S. dolichura* and *P. bougainville* have been seen to inhabit similar environments, but are also known to occur in heathlands where *P. shortridgei* and *P. apicalis* both predominate. Walton (1988) reports that *P. bougainville* prefers to hunt on stony ridges and sandhills, or plains behind beaches. *P. australis* occupies a temperate rocky desert while *P. gouldii* inhabits hummocky grasslands. *S. hirtipes* and *S. psammophila* are also known to inhabit grasslands, but are common to sandhills and plains. *S. hirtipes* has also been recorded in woodlands and on alluvial plains and is adapted for locomotion on sandy surfaces (Walton 1988) (Table 7). These species suggest a more arid palaeoenvironmental setting. This is supported by the sharp change in clay mineral type from the gypsiferous red-brown clays to the gypsiferous chocolate brown clays. The change indicates a drying and erosion of nearby mudflats previously indicated by detrital gypsum only. Several pre-European disharmonious species pairs have again been observed at this stratigraphic level (Appendix I). Allopatric species pairs suggest a more equitable environment than exists at present (Lundelius 1983). Temperate heath and forest dwelling species are seen to have coexisted with several sandy and rocky desert dwelling species, hummock grassland dwelling species and open heath dwelling species. The faunal assemblage deduced from level C suggests a more arid variable environment dominated by open woodlands that lack an under storey and are interspersed with grassland-heathland and rocky or alluvial surfaced patches.

The faunal composition of level B is similar to the previous level with the addition of *P. bolami*, an arid zone species, and the loss of *P. occidentalis*, *P. apicalis* , *D. geoffroii* and *T. cynocephalus*, scrubland/heathland and ubiquitous species (Walton 1988). These species have only been recorded in small numbers so their presence or absence may be a chance event. Several allopatric species pairs similar to level C exist on level B (Appendix I). The addition of more arid species supports the hypothesis that the environment became drier, and that forests become more open, losing its understorey while grassland, heathland and sandy or alluvial surface patches become more prominent.

The fauna of level A suggests another change in palaeoenvironmental conditions (Table 7). The continued presence of *R. fuscipes*, *B. penicillata* and *M. eugenii* suggests a patchy temperate coastal forest still exists. The reappearance of *I. obesulus* may be interpreted as a shift in the understorey vegetation from the open community preferred by *P. bougainville* to a more closed community with greater ground cover. The presence of a single *Macrotis lagotis* individual suggests that a sandy or alluvial plain may still exist nearby. No disharmonious pairs exist at this stratigraphic level suggesting the environment may be approaching those characteristics seen in the present. The faunal composition for this level suggests a shift towards a more dense vegetation community as was previously inferred for Level D and E.

CONCLUSIONS

The evidence compiled from the study of the sedimentology and palaeontology of Black's Point sinkhole has enabled a palaeoenvironmental reconstruction spanning the last 4500 years. It indicates three major periods of accumulation. Prior to 4000BP the fauna present suggest that the climate for the Venus Bay region was wetter, more temperate and less variable than at present. The vegetation was dominated by forest-woodlands with a thick understorey, while a mudflat area existed within the bay. Around 4000BP evidence suggests that effective precipitation or water availability decreased and environmental conditions became drier and more variable. This resulted in a more open woodland with a decreased understorey density, and drying and erosion of mudflats. Around 1000BP it appears the region became slightly wetter and environmental conditions became less variable. This would allow forests to recover slightly, becoming more closed with a thicker understorey.

Evidence in the literature relating to sites across Australia lends support the palaeoenvironmental synthesis proposed from the Black's Point sinkhole data. Several authors (Bowler 1981; Kershaw 1983; Bowler and Wasson 1984; Chivas et al. 1985; COHMAP 1988; Shulmeister 1992; Chivas et al. 1993; Barnett 1994; Williams 1994) report wetter periods from 7500–4500BP for the Australian region, with drier conditions occurring between 3500–2000BP, and a climatic recovery taking place 2000–1000BP.

The community composition of the Black's Point sinkhole fauna appears to be a mixture of western and eastern species, but it most closely resembles the Nullarbor Plain and associated coastal fauna deduced by Baynes (1987). This implies a greater range for the Nullarbor coastal community, extending it to the eastern side of the Great Australian Bight.

Taphonomic analysis indicates that Black's Point sinkhole has operated as a pitfall trap during the Late Holocene. The fossil fauna identified in the sinkhole is considered a good representation of the terrestrial palaeocommunity that populated the Venus Bay coastal regions prior to European settlement.

The Black's Point sinkhole fauna includes the youngest occurring mainland specimen of *Thylacinus cynocephalus*. It suggests that Thylacine populations that once ranged across southern Australia began to retreat eastward approximately 3000BP before becoming extinct on the mainland and later in Tasmania. An Accelerator Mass Spectrometer carbon date from the tooth enamel would confirm its age.

Further palaeoenvironmental information could be obtained from the study of pollen and land snail shells in the Black's Point sinkhole strata. This could test and/or improve the resolution of the palaeoenvironmental interpretation that has been constructed from the palaeontological and sedimentological data collected. More fossil sites should also be sought out and investigated in the Eyre Peninsula region to better determine the regional pre-European faunal composition. This will be of use to DENR in their attempts to re-establish at least part of Eyre Peninsula's pre-European fauna within the Venus Bay Conservation Park.

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APPENDIX I

Allopatric species present on different levels in Black's Point Sinkhole, Venus Bay

Species Present	Allopatric pairs (Pre-Europeans)
(1) *Rattus fuscipes*	5 and 14
(2) *Pseudomys australis*	3, 5, 6, 17 and 9
(3) *P. shortridgei*	2, 5, 6, 14 and 15
(4) *P. gouldii*	5 and 17
(5) *P. bolami*	1, 2, 3, 4 and 7
(6) *P. occidentalis*	2, 3, 14 and 15
(7) *Notomys mitchelli*	5 and14
(8) *Cercartetus concinnus*	
(9) *Isoodon obesulus*	2 and17
(10) *Perameles bougainville*	
(11) *Macrotis lagotis*	
(12) *Bettongia penicillata*	
(13) *Macropus eugenii*	14
(14) *Sminthopsis hirtipes*	1, 3, 6, 7 and 13
(15) *S. psammophila*	3 and 6
(16) *S. dolichura*	
(17) *Parantechinus apicalis*	2, 4 and 9
(18) *Phascogale tapoatafa*	
(19) *Dasyurus geoffroii*	
(20) *Thylacinus cynocephalus*	